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Remote Measurement of Gaseous Pollutant Concentrations Using a Mobile Fourier Transform Interferometer System

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Research Triangle Park, NC

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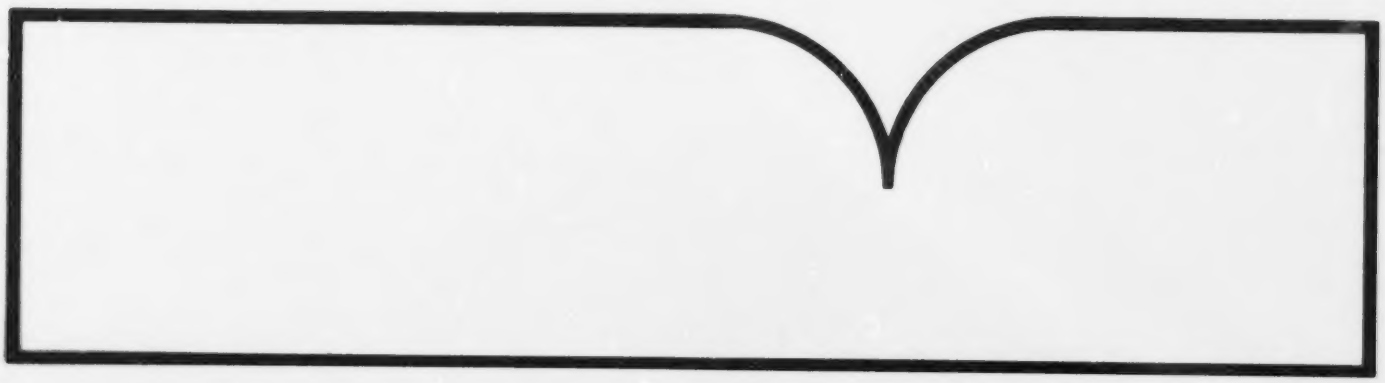

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16. ABSTRACT

A commerical Fourier transform interferometer system with telescopic optics has been installed in a van and used to make long-path absorption and single-ended emission measurements of gaseous pollutant concentrations at a number of geographical locations. The system covers the infrared spectral region from 650 to 6000 cm^{-1} at a maximum resolution of 0.06 cm^{-1}. For many pollutants, concentrations in the 1-10 parts per billion range can be detected over a 1 kilometer path length. To date, measurements have been made in the absorption mode across fertilizer plant gypsum ponds, an oil refinery, and jet engine plumes; industrial stacks, waste gas flares, and jet engine plumes have been studied in the emission mode.

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Remote measurement of gaseous pollutant concentrations using a mobile Fourier transform interferometer system

William F. Herget and James D. Brasher

A commercial Fourier transform interferometer system with telescopic optics has been installed in a van and used to make long-path absorption and single-ended emission measurements of gaseous pollutant concentrations at a number of geographical locations. The system covers the IR spectral region from 650 cm^{-1} to 6000 cm^{-1} at a maximum resolution of 0.06 cm^{-1}. For many pollutants, concentrations in the 1–10-ppb range can be detected over a 1-km path length. To date, measurements have been made in the absorption mode across fertilizer plant gypsum ponds, an oil refinery, and jet engine plumes; industrial stacks, waste gas flares, and jet engine plumes have been studied in the emission mode.

I. Introduction

In early 1968, the National Air Pollution Control Administration (later to become a part of the EPA) recognized the need for advanced instrumentation that could identify and measure the concentrations of gaseous pollutants emitted by various types of sources. It was determined that an IR spectrometer system capable of making (1) long-path (~1-km) absorption measurements in the atmosphere and (2) single-ended remote emission measurements of stack effluents would be a particularly suitable instrument for characterizing the emissions from various sources. Specifically, such measurements would require no prior knowledge of anticipated species, no sample handling, and the spectral signatures of interfering species as well as particular pollutants could be determined simultaneously. It was anticipated that these later measurements would provide background data for the development of simple pollutant-specific IR measurement systems.

Such an instrument, called the ROSE (Remote Optical Sensing of Emissions) System, was developed for EPA by General Dynamics/Convair under the direction of Ludwig.[1,2] The original system utilized a blackbody radiation source, Dall-Kirkham telescopic optics, a quarter-meter linear-wavenumber-drive monochromator, and a cryogenically cooled Hg:Ge detector to cover the 800–5000-cm^{-1} spectral region. For long-path measurements, this system provided a spectral resolution of about 1 cm^{-1}. For single-ended emission measurements of industrial stack effluents (temperature on the order of 400 K) the highest achievable resolution compatible with a reasonable SNR was about 10 cm^{-1}. Despite these resolution limitations, a number of successful measurements were carried out on the CO fundamental band at 2145 cm^{-1} and on the SO_2 combination band at 2500 cm^{-1}. However, it was realized that a significant improvement in spectral resolution was needed to allow successful implementation of the long-path absorption/emission measurement concept. Accordingly, in late 1975 a decision was made to replace the grating monochromator and its associated detector and electronics with a Fourier transform interferometer system. For a complete discussion of various remote sensing methods and applications, the reader is referred to Refs. 3 and 4.

II. ROSE System

A schematic of the ROSE optical system is shown in Fig. 1. The light source–telescope system used for the long-path absorption measurements is shown in Fig. 2. The $f/5$ scope is of Dall-Kirkham configuration with a 30-cm diam primary mirror. The light source is a 1000-W quartz–iodine lamp. This lamp provides considerably more near-IR energy than the 1500 K blackbody previously used, and in wavelength regions where the quartz envelope is opaque, its thermal emission provides sufficient energy. In addition, the intense visible energy from this source aids system alignment. Generally, the light source and telescope system are installed in the back of a pickup truck and driven to a desired location; a small generator powers the light source if local power is not available.

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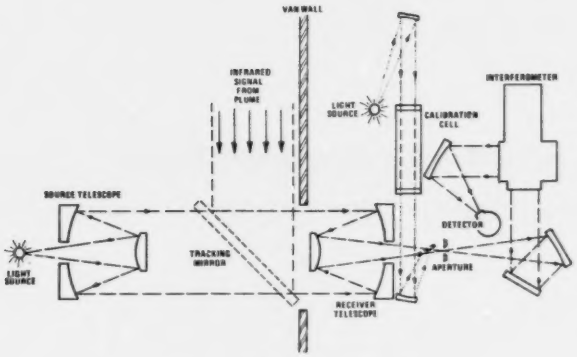


Fig. 1. ROSE optical system.

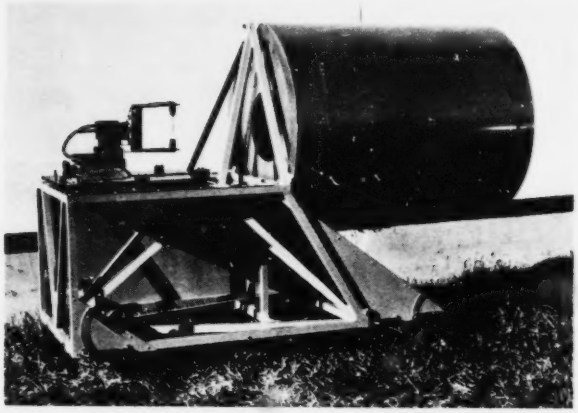


Fig. 2. ROSE system light source-telescope.

Fig. 3. ROSE system tracking mirror.

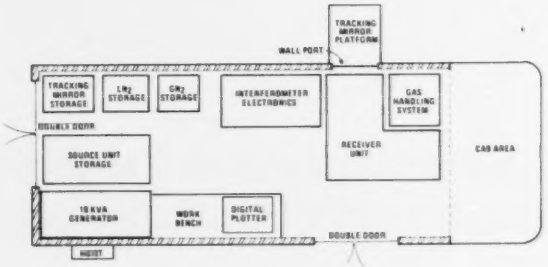


Fig. 4. Layout of ROSE system in van.

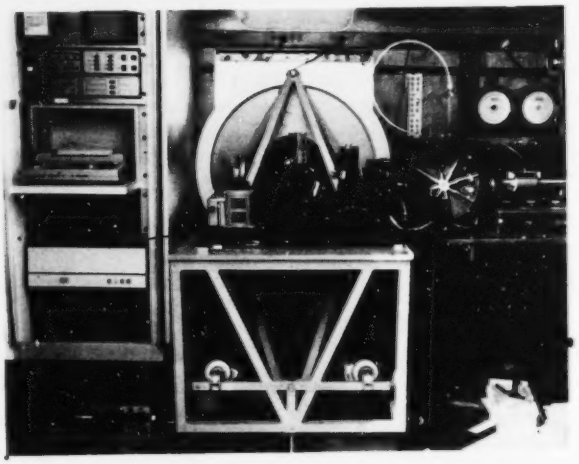


Fig. 5. ROSE system.

The remainder of the ROSE system is installed in an 8.5-m van. A telescope identical to that described above collects energy from the remote light source directly through a port in the side of the van, as indicated in Fig. 1. To measure the radiation signal from stack effluents, an elliptically shaped flat mirror (called the tracking mirror in Fig. 1) reflects energy through the port into the telescope. The tracking mirror is mounted on a platform attached to the side of the van (Fig. 3). The receiver telescope focuses energy (in either mode of operation) at the interferometer aperture, which is adjustable for compatibility with desired spectral resolution. The interferometer and peripheral equipment comprise a standard Nicolet Instrument Corporation model 7199 FT-IR system configured to fit into the van. Major components of this system consist of a computer with 40K memory, dual-density disk with 4.8-million 20-bit word capacity, teletype, paper tape reader, oscilloscope interactive display unit, and a high-speed digital plotter. Maximum spectral resolution achievable with this system is 0.06 cm^{-1}.

The interferometer itself is mounted on the telescope support structure. All other systems (except the plotter) are arranged in two 19-in. (48-cm) relay racks. The general layout of the van is shown in Fig. 4, and a major portion of the interferometer system is shown in Fig. 5. Two beam splitters, KBr and BaF_2, are available for use

in the interferometer. A dual-element sandwich-type detector is mounted in a liquid nitrogen Dewar. For the 1800–6000-cm^{-1} region InSb is used, and HgCdTe is used from 600 cm^{-1} to 1800 cm^{-1}; the two regions are scanned separately.

For the long-path absorption measurements, initial alignment of the telescopes is achieved by visually boresighting each at the other. Final alignment is made by maximizing source signal level at the interferometer aperture with the assistance of two-way radios. For stack emission measurements, alignment using the tracking mirror is obtained by boresighting and by observing the image projected by the telescope. The tracking mirror can be adjusted manually from inside the van about the telescope axis and a vertical axis. This alignment system is sufficiently precise to allow manual tracking of the sun for solar absorption measurements.

Auxiliary equipment carried in the van includes a weather station for recording wind velocity and temperature and a laser range finder for measuring path lengths. For stability in the long-path configuration four jacks are lowered from the van chassis to the ground. The interferometer itself is leveled within the van. Power for the ROSE system, including that needed for heating or air conditioning, is supplied by a 10-kW generator. For data collection, the generator is lowered from the van to the ground using an electrically operated winch. This procedure is necessary to avoid electrical and mechanical interference with the operation of the interferometer. During transportation of the van to a field site, two precautions are observed: the beam splitter is removed from the interferometer, and the disk drive head is clamped back away from the disk. After reinsertion of the beam splitter, the interferometer can usually be realigned in a matter of minutes. An initial setup of the entire system requires 2–3 h. Subsequent setups in the same vicinity require about 1 h under normal conditions.

III. System Calibration

The calibration of the ROSE system for long-path measurements follows the conventional procedure of obtaining the spectra of known concentrations of desired species (broadened to atmospheric pressure) contained in a sample cell (shown in Fig. 1). Usually some preliminary spectra are obtained prior to a field trip. The final calibrations are made after the field trip in order to match instrument resolution and sample absorption with field measurement conditions. A vacuum transfer system with appropriate gauges is used in filling the cell to desired pressures. Cells ranging in length from 1 cm to 200 cm are available.

In order to obtain an intensity calibration of the emission spectra due to hot gases, a blackbody source operated at known temperature is caused to fill the interferometer field of view and its spectrum recorded. System software has the capability of generating the Planck blackbody radiation function for any desired blackbody temperature. By dividing the blackbody spectrum by the appropriate Planck function, an instrument response function is obtained. An emission spectrum obtained from a plume or flame (that also fills the interferometer field-of-view) can be divided by the instrument response function. This result can then be plotted in terms of spectral radiance [W (cm^2 sr $cm^{-1})^{-1}$]. If the temperature of the hot gas plume can be determined, a Planck blackbody function can be generated at the temperature of the plume, divided into the spectral radiance curve, and this result plotted to yield spectral emissivity as a function of wavenumber. (All these operations are carried out using standard system software.) Then, if the spectral absorption coefficient of the species in question is known as a function of temperature, the gas concentration can be calculated. The determination of the plume temperature from its emission spectrum can be a complex problem in itself; a subsequent paper will treat this problem.

IV. Measurement Programs

During the period from August 1977 through June 1978, the ROSE system was used to make measurements at a number of different types of pollutant sources:

A. Gypsum Ponds

The first field use of the ROSE interferometer system was at a phosphate fertilizer plant gypsum pond. A series of these ponds are used at fertilizer plants for waste water treatment. The ponds, which are generally rectangular in shape with boundary dimensions as long as 1 km, are particularly suitable for long-path measurements. The particular environmental problem presented by these ponds is that they give off gaseous fluorides. In past studies using wet chemistry sampling methods, it has been possible to measure only total fluorides. Analysis of the pond chemistry indicates that expected gaseous fluorides would be SiF_4 and/or HF.

A series of measurements were made at various locations around several ponds with path lengths ranging from 500 m to 1000 m. Typical spectra obtained are shown in Fig. 6. The upper spectrum was taken over a 900-m path at a location presumed to be free of HF. The middle spectrum was taken over an 860-m path across a gypsum pond. Both spectra were taken with a resolution of 0.125 cm^{-1}. Using system software, these spectra were expressed in absorbance, subtracted, and the result converted back to transmittance. This result is shown in the lower spectrum. The subtraction eliminates the effect of the weak atmospheric absorption seen in the upper spectrum at 4173.9 cm^{-1}. Using an HF line strength of 3.48E–19 cm^{-1} (molecules $cm^{-2})^{-1}$ (Ref. 5) and a halfwidth of 0.04 cm^{-1},[6] the HF concentration was determined using the equivalent-width method. The calculations were carried out with an existing computer program.[7] For the HF line shown, the path-averaged concentration was determined to be 45 ppb. (It was not possible to calibrate the HF spectrum with the sample cell method since our gas handling system is not resistant to HF.) Absorption due to the SiF_4 fundamental band centered at 1031.5 cm^{-1} could

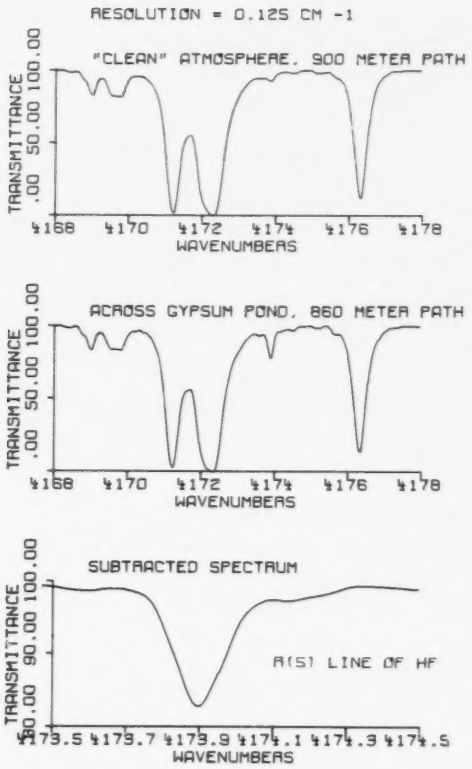


Fig. 6. Gypsum pond spectra, 4168–4178 cm^{-1}.

not be detected. Calibration spectra indicated that 0.5 ppb of SiF_4 would have produced about 2% absorption over an 860-m path, and this value is taken as a reasonable lower sensitivity limit.

B. Jet Engines

In order to obtain some basic data on jet engine emissions as well as to learn how the interferometer would perform in a high-noise-level environment, a series of measurements were made at Tyndall Air Force Base, Florida, in cooperation with personnel of the Air Force Civil and Environmental Engineering Development Office. Three measurement configurations were selected: (1) to measure the absorption of the exhaust of a single jet engine, the light source and ROSE van were located so as to provide an optical path perpendicular to the engine axis and 10 m downstream of the nozzle exit (this particular engine was on a test stand), with the van being about 80 m from the engine; (2) to measure the emission signal from a single engine, the receiver telescope was aimed at the nozzle exit plane of an engine being operated in a tethered aircraft, with the van being about 60 m from the aircraft; (3) for a long-path absorption measurement the ROSE van and light source were separated by 900 m, and the optical path was parallel to a taxiway.

Measurements were made in (1) and (2) with the engines operated at idle, military, and afterburner power. During the measurements on the exposed engine (1), it was found that for military and after burner power levels the interferometer operation was severely affected by acoustical noise, and the data were useless. For the engine in the aircraft (2), only afterburner operation affected instrument performance. Although time did not permit additional measurements, it was felt that if the ROSE van were located at least 200 m from the engines, good spectra could be obtained under any operating conditions.

Samples of emission spectra obtained in the 2100–2400-cm^{-1} spectral region at idle and military power are shown in Fig. 7. Noteworthy spectral characteristics are CO emission at idle and lack of CO emission at military power. Absorption spectra obtained at idle power are shown in Figs. 8–11; in each figure a clean atmospheric absorption spectrum is shown for reference. The calculated concentrations, based on a plume diameter of 10 m, are given in Table I. During the time slot allotted to the long-path measurements, there was not much aircraft activity due to a number of rain squalls. The spectra obtained did show CO at about 0.6 ppm and also the hydrocarbon continuum with an equivilant hexane concentration of about 0.09 ppm. These latter spectra, along with the plume CO absorption spectrum, are rather conventional and are not shown. It is realized that the acetelyne identification (Fig. 8) is tentative due to the weak signal and interference with CO_2 absorption.

The concentrations determined in these measurements were compared with typical results obtained on the same type jet engine by probe sampling methods.[10] For the probe measurements, species concentrations were calculated to be 275 ppm m for CO and 440 ppm (carbon) m, where the hydrocarbon continuum concentration has been expressed in terms of ppm of carbon. This is in good agreement with the optical values of 280 ppm m for CO and 520 ppm (carbon) m (8.6 ppm × 6 atoms carbon × 10 m) for the hexane equivalent. Also, the ratio of ethylene to total hydrocarbons in typical probe measurements is given as 0.15, and the optically determined ratio is 0.12.

C. Oil Refinery Measurements

Large industrial complexes, such as oil refineries, are considered as extended-area sources of pollutants. In other words, the pollutants from such complexes are generally a mixture of emissions from stacks, leaks, etc. and are classified as fugitive emissions. Determining the total emissions by conventional point monitors at such a complex source would be very difficult and time consuming, if possible at all. Thus, one of the primary goals of our laboratory remote sensing program is to develop the methodology for remote measurement of mass emission rates for extended area sources. This methodology would include remote measurement of wind velocity, as well as remote measurement of species concentrations.[3] In order to obtain some basic data on the ability of the ROSE system to measure emissions from such a source, a series of measurements were conducted at an oil refinery.

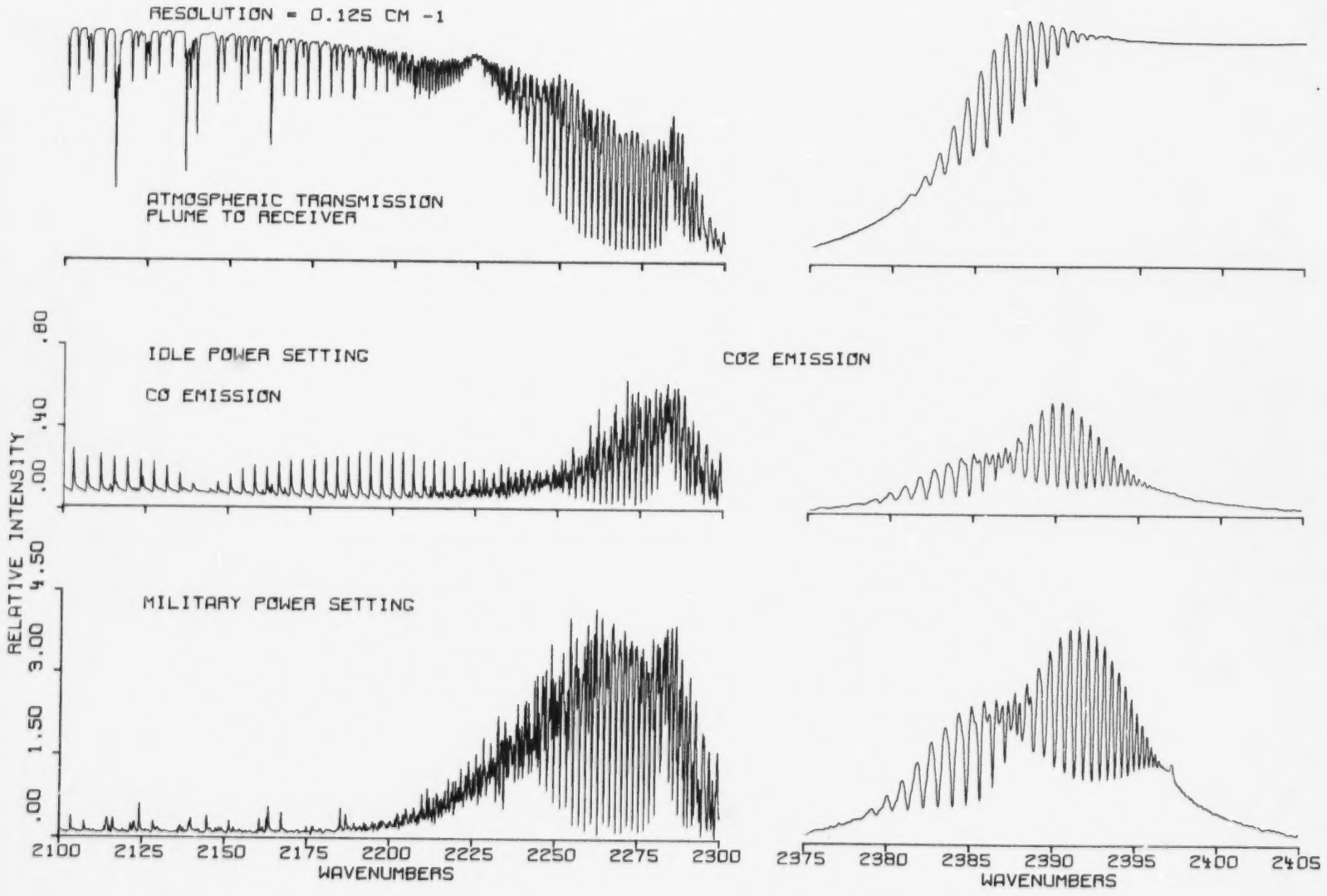


Fig. 7. Jet engine emission spectra, 2100–2400 cm^{-1}.

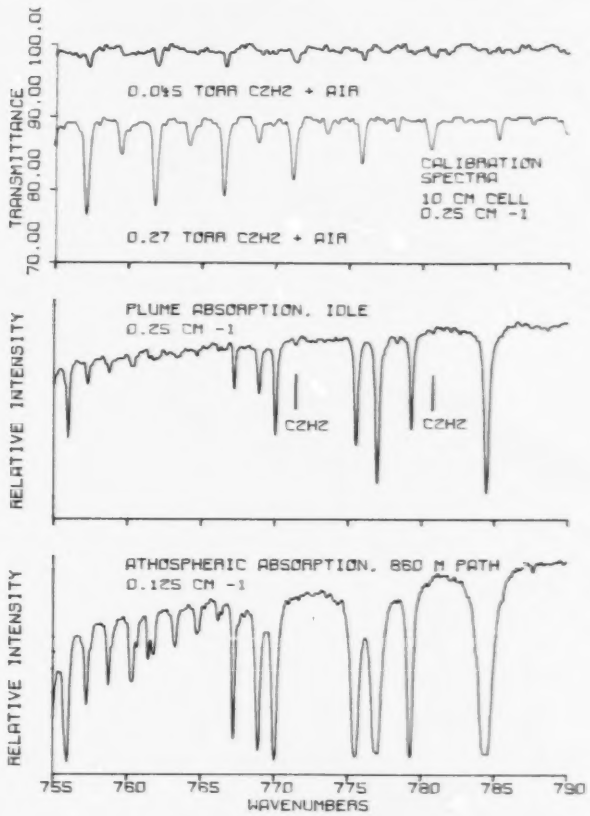


Fig. 8. Jet engine absorption spectrum, 755–790 cm^{-1}.

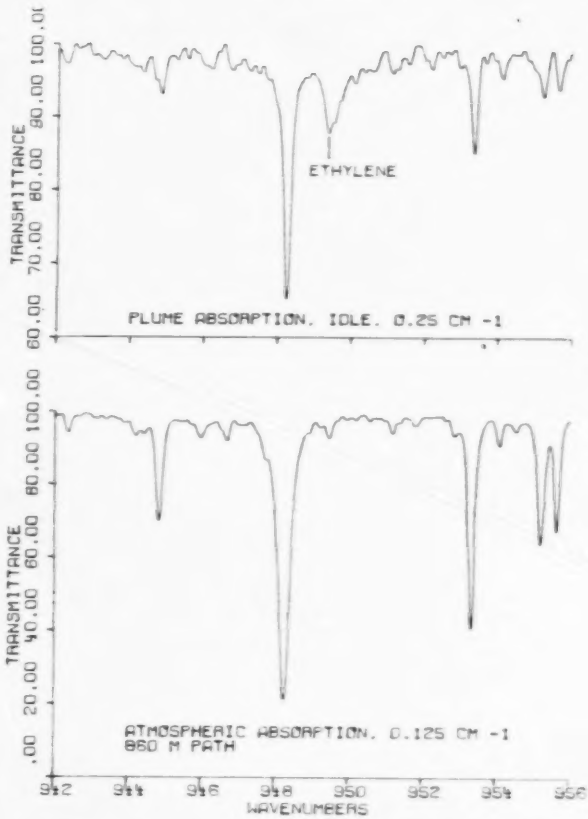


Fig. 9. Jet engine absorption spectrum, 942–956 cm^{-1}.

Fortunately, it was possible to make our initial measurements at a refinery situated in a valley. In this way a portion of the 1440-m optical path for absorption measurements was above the height of most of the refinery stacks. The site for the light source unit was reachable only by a four-wheel-drive vehicle, but power was available. The van was located on refinery property. The optical path was across the northern boundary of the refinery, so that winds with a southerly component would blow refinery emissions through the optical path.

Typical absorption spectra obtained at different times are shown in Figs. 12–15. The calculated concentrations are given in Table II. The ambient temperature during these measurements was generally below freezing, so the water vapor concentration was much less than normally encountered. Because of low temperatures and high winds, the quartz–iodine light source operated at cooler external temperature than in previous measurements, and the long wavelength spectra have a poorer SNR than the short wavelength spectra. Although the SO_2 band at 2500 cm^{-1} is appreciably weaker than that at 1150 cm^{-1}, it is more suitable for concentration determination in these measurements because there is essentially no interference from other species. It is of interest to note that the hydrocarbon continuum absorption in the 2800–3100-cm^{-1} region has the same general shape, whether it be due to oil refinery emissions, jet engine or automobile engine emissions, or kerosene vapor. The strong continuum observed indicates that more hydrocarbons than ethylene, propylene, and methanol probably are present; time has not permitted analyses for other species. From similar spectra (not shown) the CO concentration was determined to be about 0.35 ppm. For methane, the line cluster at 2742.5 cm^{-1} was selected for analysis as there appears to be no water vapor interference. Calibration spectra were obtained under several conditions: 0.125 cm^{-1} to match the gypsum pond spectrum; 0.125 cm^{-1} degraded by use of a medium size aperture to match the 11:23:04 refinery spectrum; and 0.5 cm^{-1} to match the 17:24:25 refinery spectrum. The concentrations obtained were:

gypsum pond—1.6 ppm;
oil refinery (11:23:04)—2.2 ppm;
oil refinery (17:24:25)—4.2 ppm.

The emission spectra obtained by sighting on two refinery stacks, a sulfur recovery unit and a CO boiler, are shown in Figs. 16 and 17. The sulfur recovery unit is characterized by strong CO and SO_2 emission and

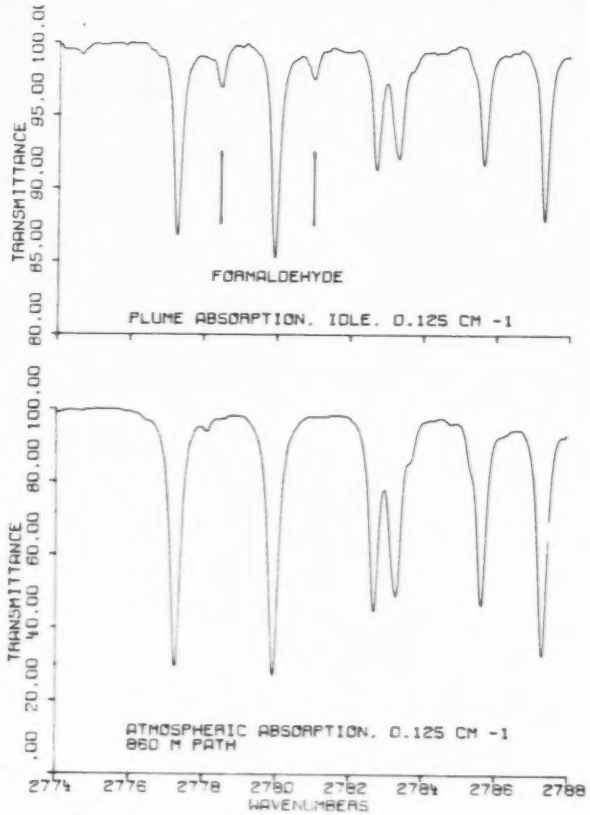


Fig. 10. Jet engine absorption spectrum, 2774–2788 cm^{-1}.

weak CO_2 emission; an intensity calibration on this spectrum is not given, since the plume did not fill the instrument field of view. The CO boiler spectrum is characterized by strong CO_2 and H_2O radiation and weak CO and SO_2 radiation. The CO_2 optical depth in this spectrum is sufficiently large that there is essentially blackbody radiation at 2225 cm^{-1} where the cold atmospheric CO_2 does not absorb. This greatly simplifies a temperature calculation. The value obtained was 600 K, which is in reasonable agreement with a nominal stack gas temperature of 650 K. Temperature calculations based on the line intensities of the 960-cm^{-1} CO_2 band will be reported in the near future.

D. Power Plant Spectra

A series of spectra were obtained at a coal-burning power plant. The ROSE van was located approximately 800 m from the stack. The stack diameter was 6 m, the nominal effluent temperature was 400 K, and the visual opacity of the plume was approximately 10%. Typical plume emission spectra are shown in Figs. 16 and 17. In addition to the typical plume species, emission due to HCl was observed; the calculated concentration was about 50 ppm.

The SO_2 concentration was calculated (using the 1150-cm^{-1} band) as 940 ppm ± 10%. In-stack measurements of SO_2 concentrations were made using conventional sampling techniques. However, the concentrations varied by an order of magnitude and are considered unreliable. Several spectra were taken when the sun was behind the plume. A portion of this spectrum is shown in Fig. 18 along with a solar spectrum, presumably free of SO_2. These spectra were expressed in absorbance and subtracted. The result shows clearly the SO_2 absorption. The optical path through the plume was about 60 m downwind from the stack exit. The SO_2 concentration was calculated to be 1300 ppm-m. The absorption coefficient data for these calculations were taken from the work of Burch.[11]

A portion of a solar spectrum taken soon after sunrise is shown in Fig. 18; the remainder of this spectrum is shown in Fig. 19. Most of the strong lines are due to H_2O. Other easily recognized features are due to CO_2, O_3, and N_2O. The presence of HNO_3 absorption was pointed out to us by A. Goldman (University of Denver). Two lines due to Freon-12 are also identified.

It was possible to observe NO emission in the power plant plume. This is shown in Fig. 20, which includes laboratory NO/H_2O spectra, atmospheric transmission over a 600-m path, power plant plume emission spectra at 0.25-cm^{-1} and 0.125-cm^{-1} resolution, and also an emission spectrum from the jet engine plume (discussed previously). The NO emission lines are clearly seen in the power plant spectra in regions of atmospheric windows. The apparently weaker NO signal in the 0.125-cm^{-1} spectrum, as compared with the 0.25-cm^{-1} spectrum (this is especially notable for the Q-branch at 1876 cm^{-1}), is attributed to a higher water vapor content in the atmosphere when the higher resolution spectrum was obtained as compared with that for the lower resolution spectrum. An emission spectrum from the jet engine plume at military power is also shown in Fig. 20. Although it is difficult to see in this figure, an expanded plot does show that NO emission is observable, although many of the lines are partially obscured by H_2O emission. Because of plume and atmospheric H_2O interference, NO concentration determination based solely on an emission spectrum would be difficult.

E. Vinyl Chloride Flare

Flares, whereby waste gases are burned at the top of a stack, are used in many industries as a relatively inexpensive way of converting obnoxious pollutants into H_2O, CO_2, and (in some cases) less obnoxious pollutants. The flare does present a problem in that it is difficult, if not impossible, to determine the flare efficiency by conventional sampling techniques. Thus a series of measurements were conducted with the ROSE system on a flare burning vinyl chloride to assess the potential of this method. For this particular flare, steam is injected into the exhaust gases around the perimeter of the stack exit. The effect of the steam is to improve combustion and provide a clear blue flame (invisible in the daytime); with the steam turned off, a yellow sooty flame is produced. Emission spectra due to the vinyl

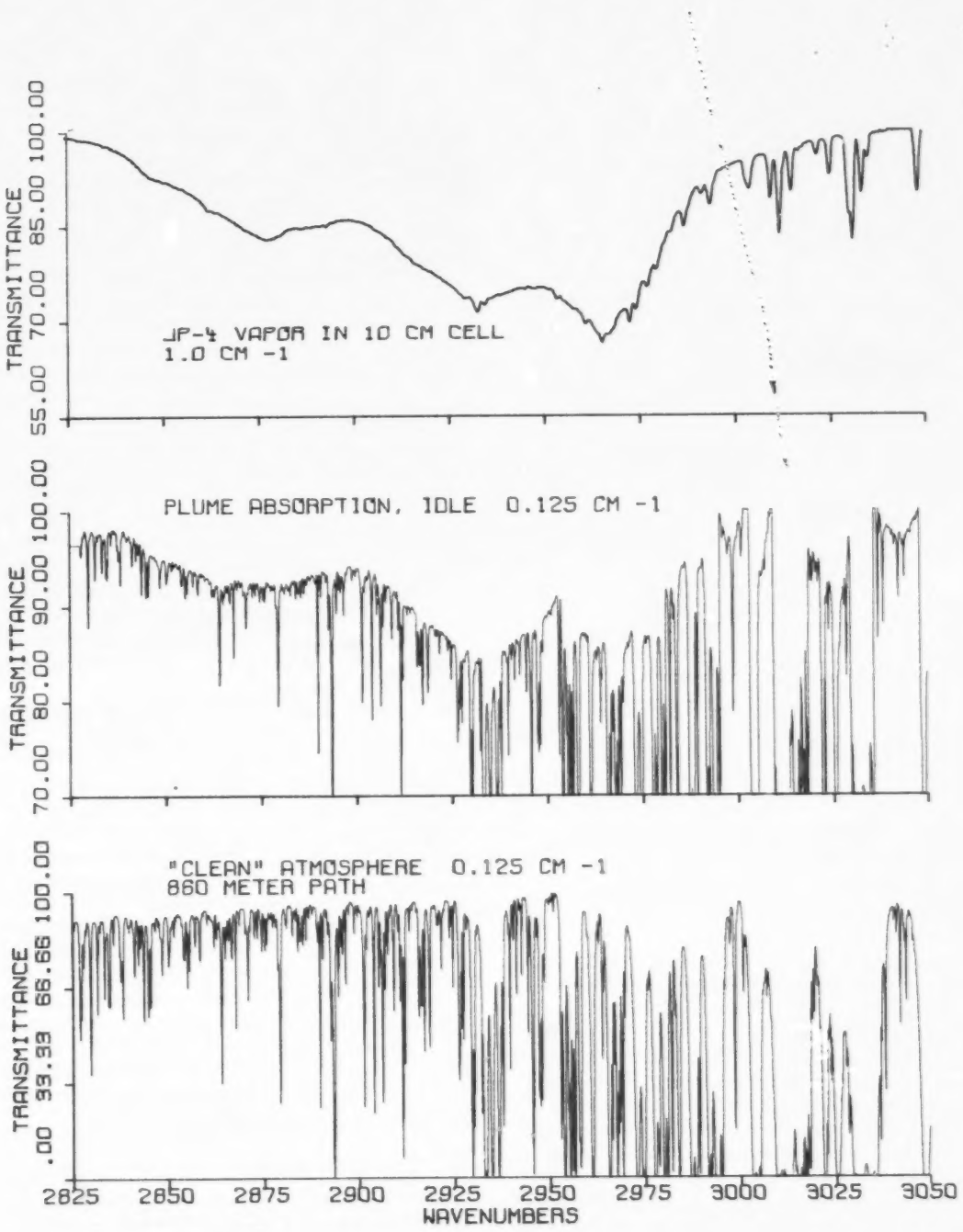


Fig. 11. Jet engine absorption spectra, 2825–3050 cm^{-1}.

Table I. Species Concentrations in Jet Engine Exhaust (10-m path)

Species	ν (cm^{-1})	$K(\nu)$ $(ppm\text{-}m)^{-1}$	Reference for $K(\nu)$	C (ppm)
Acetylene	771.5	3.4 E-3	This work	1.6
Ethylene	949.4	3.3 E-3	This work	3.2
Carbon monoxide	2176.2	3.9 E-3	This work	28
Formaldehyde	2778.4	3.6 E-3	8	0.8
Hexane equivalent	2900	6.0 E-4	9	13

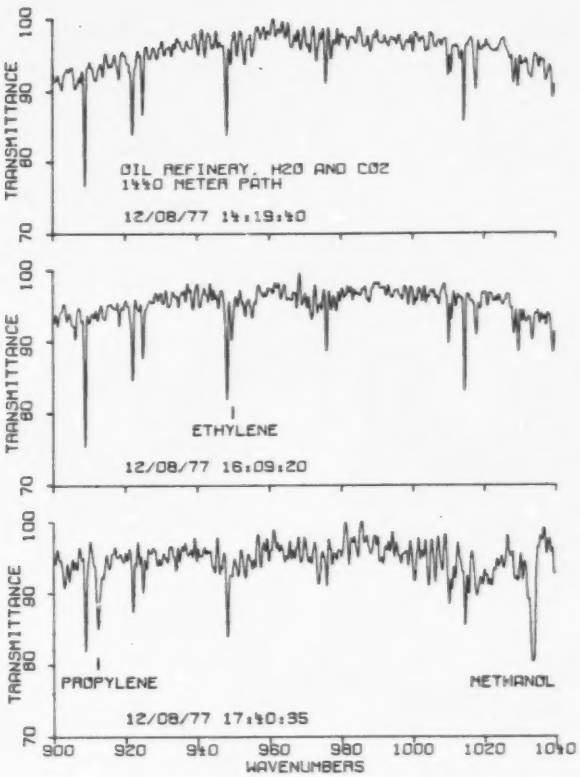
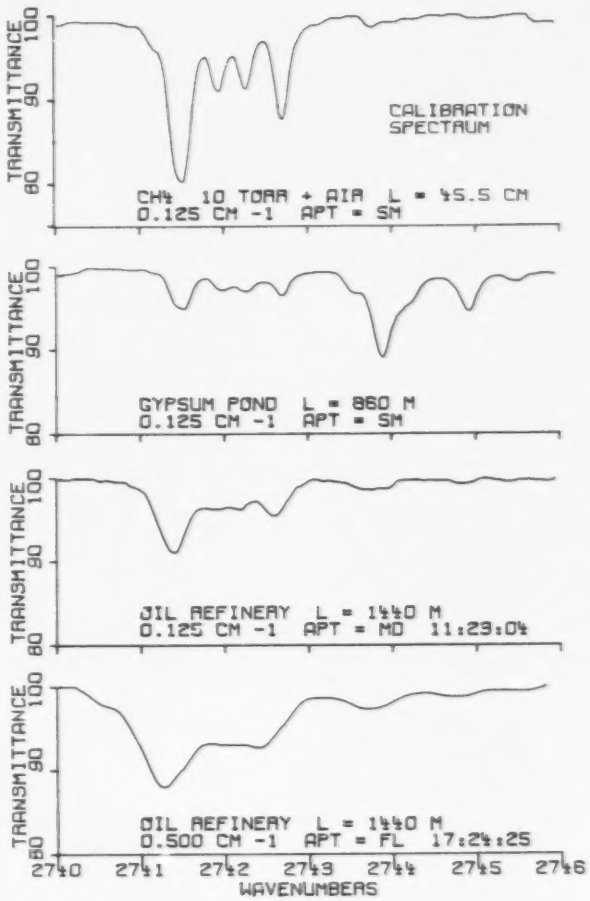


Fig. 12. Oil refinery absorption spectra, 900–1040 cm^{-1} (0.50 cm^{-1}).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OIL REFINERY L = 1440 M
0.500 CM -1 APT = FL 17:24:25
2740 2741 2742 2743 2744 2745 2746
WAVENUMBERS

Fig. 14. Oil refinery absorption spectra, 2740–2746 cm^{-1}.

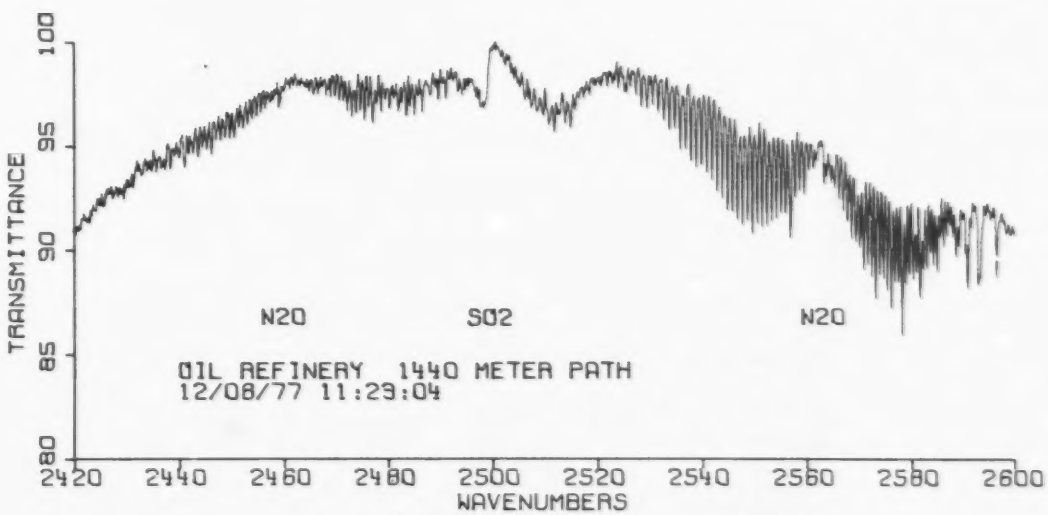

Fig. 13. Oil refinery absorption spectrum, 2420–2600 cm^{-1} (0.125 cm^{-1}).

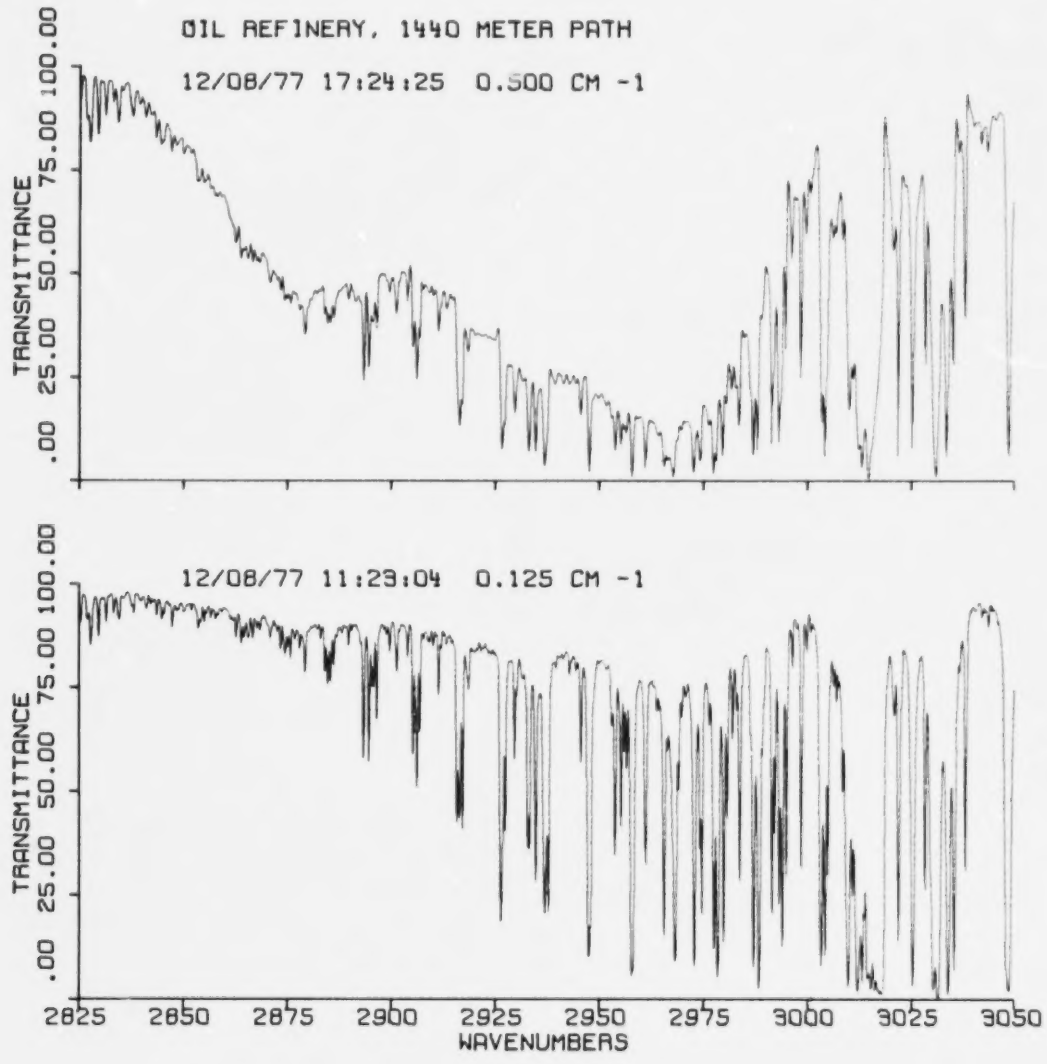

Fig. 15. Oil refinery absorption spectra, 2825–3050 cm^{-1}, at time of maximum and minimum hydrocarbon continuum.

Table II. Species Concentrations Around an Oil Refinery (1440-m path)

Species	ν (cm^{-1})	$K(\nu)$ $(ppm\text{-}m)^{-1}$	Reference for $K(\nu)$	C (ppm)
Propylene	912.3	1.10 E-3	This work	0.081
Ethylene	949.4	3.3 E-3	This work	0.011
Methanol	1033.5	1.7 E-3	9	0.080
Sulfur dioxide	2500	3.5 E-5	This work	1.0
Methane	2741.5	3.5 E-5	This work	[a]
Hexane equivalent	2900	6.0 E-4	9	0.86

[a] See discussion in text.

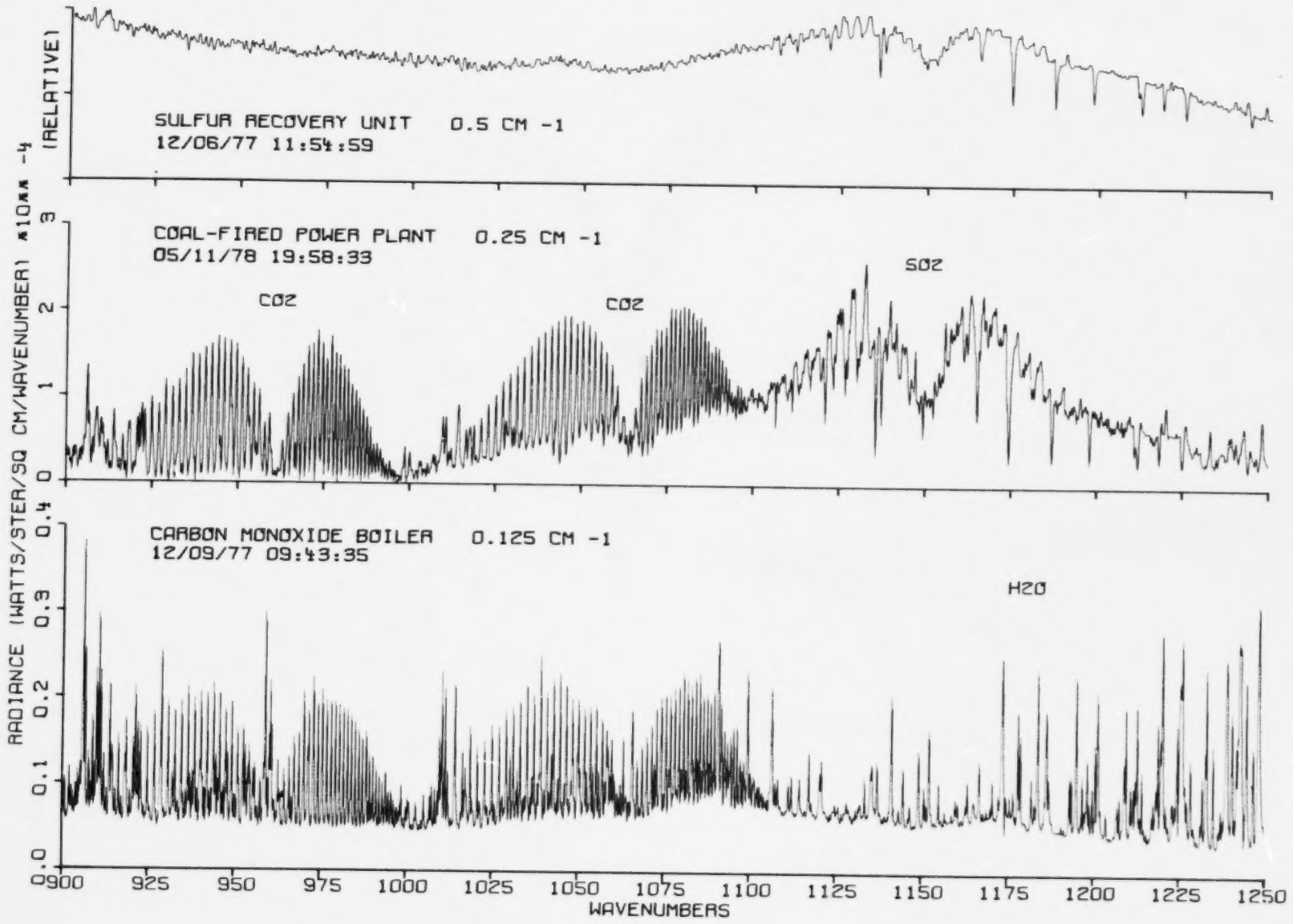

Fig. 16. Industrial stack emission spectra, 900–1250 cm^{-1}.

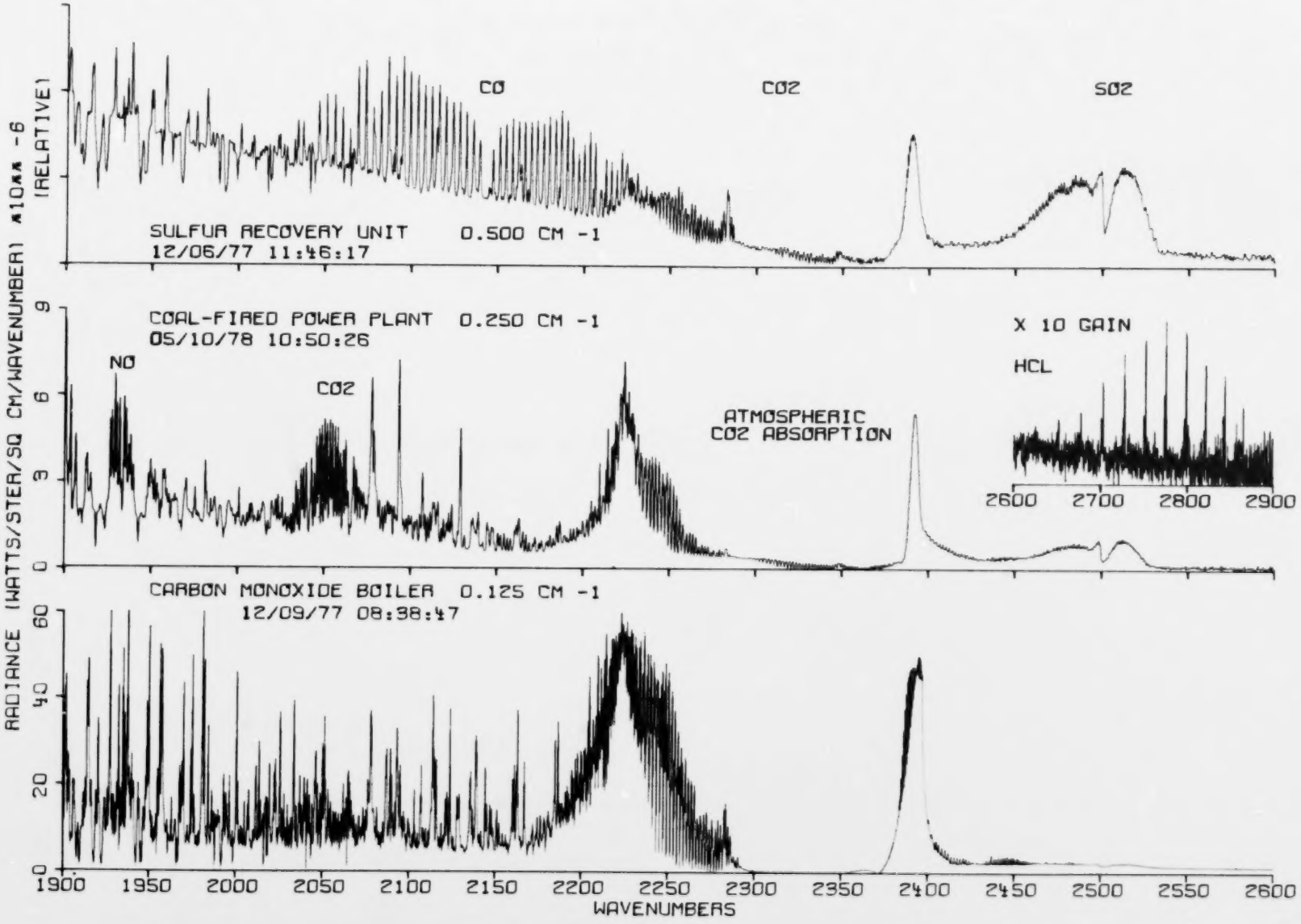

Fig. 17. Industrial stack emission spectra, 1900–2900 cm^{-1}.

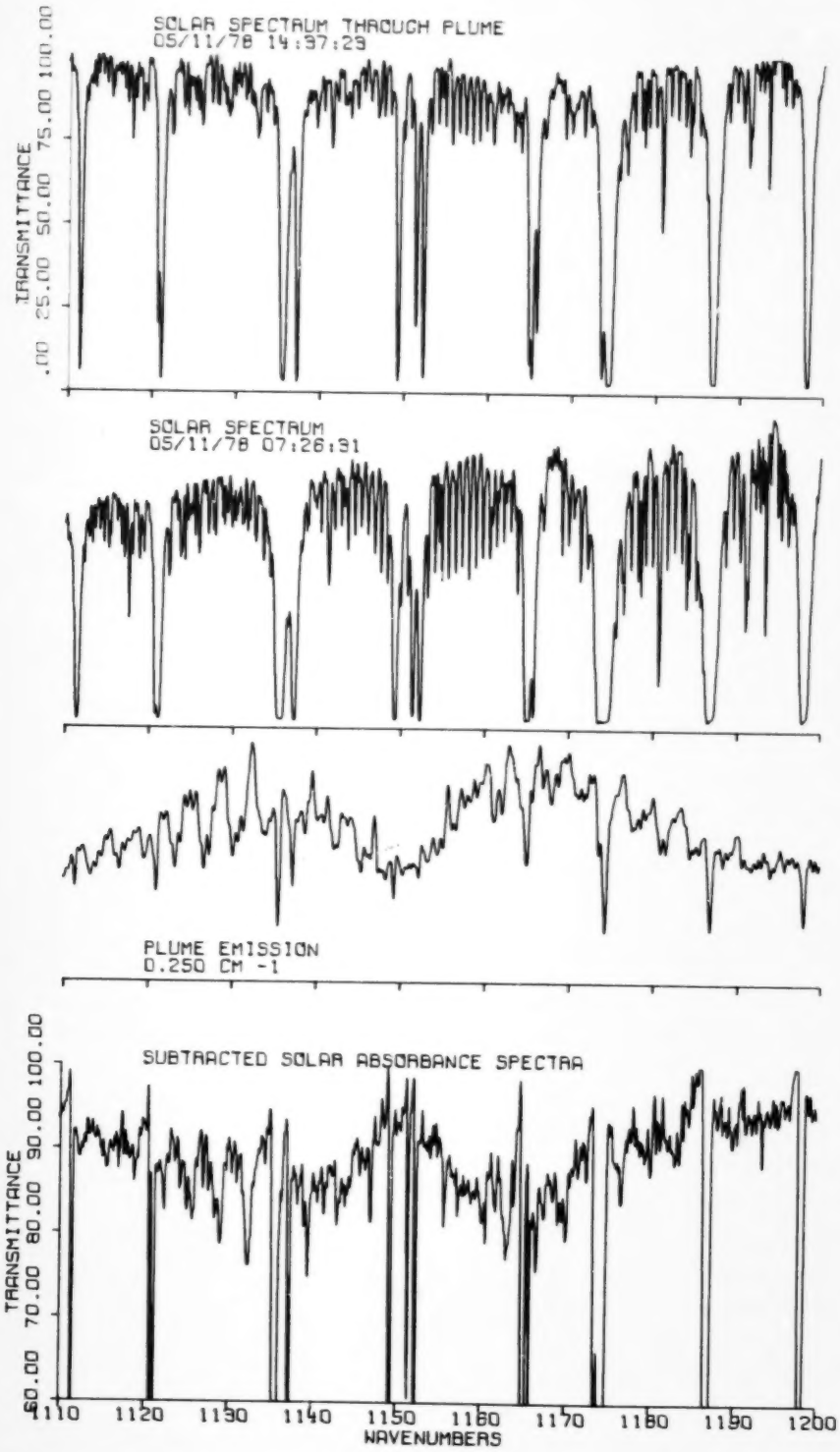

Fig. 18. Power plant plume absorption of solar radiation, 1110–1200 cm^{-1}. (A plume emission spectrum showing SO_2 is included for reference.)

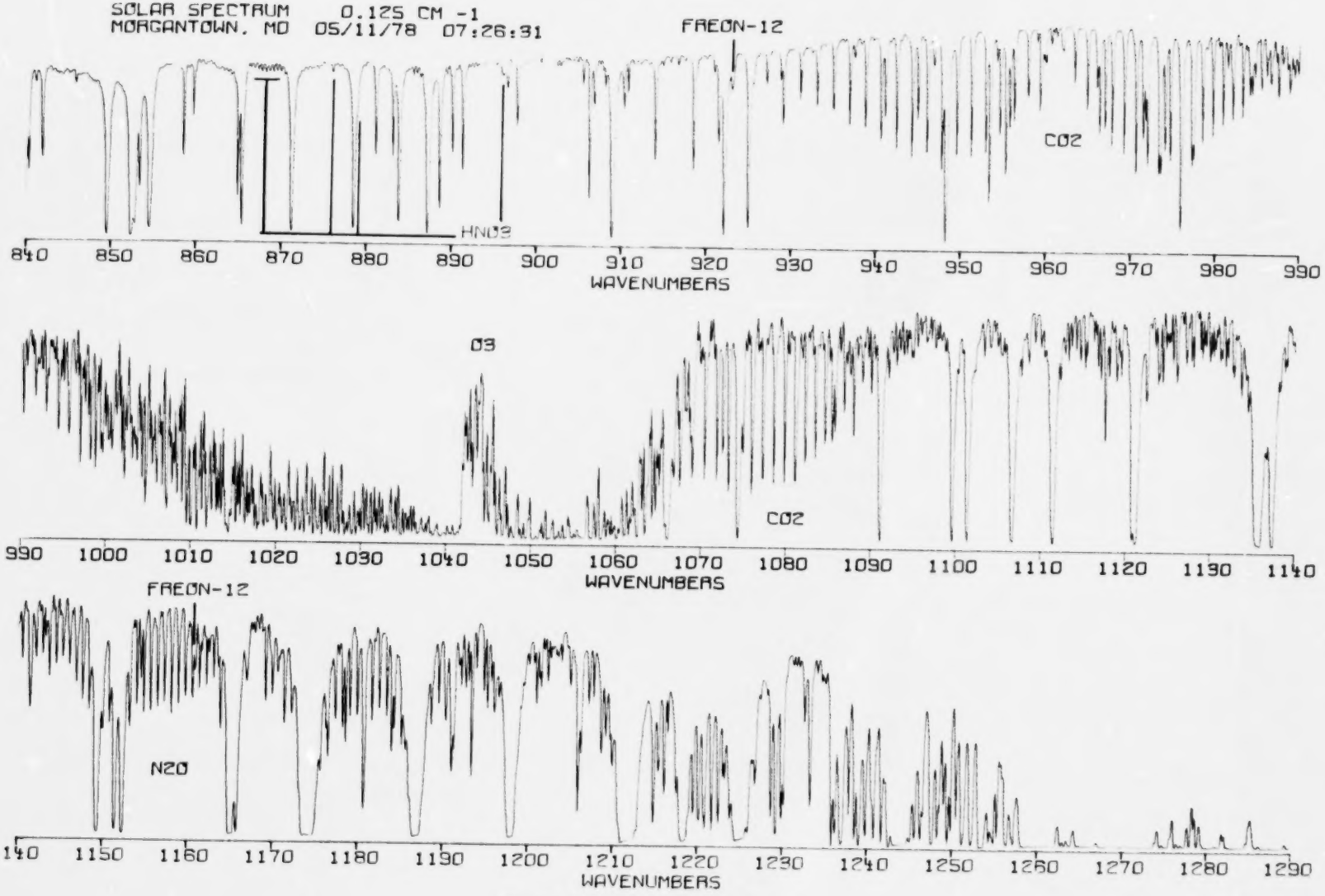

Fig. 19. Solar spectrum, 840–1290 cm^{-1}.

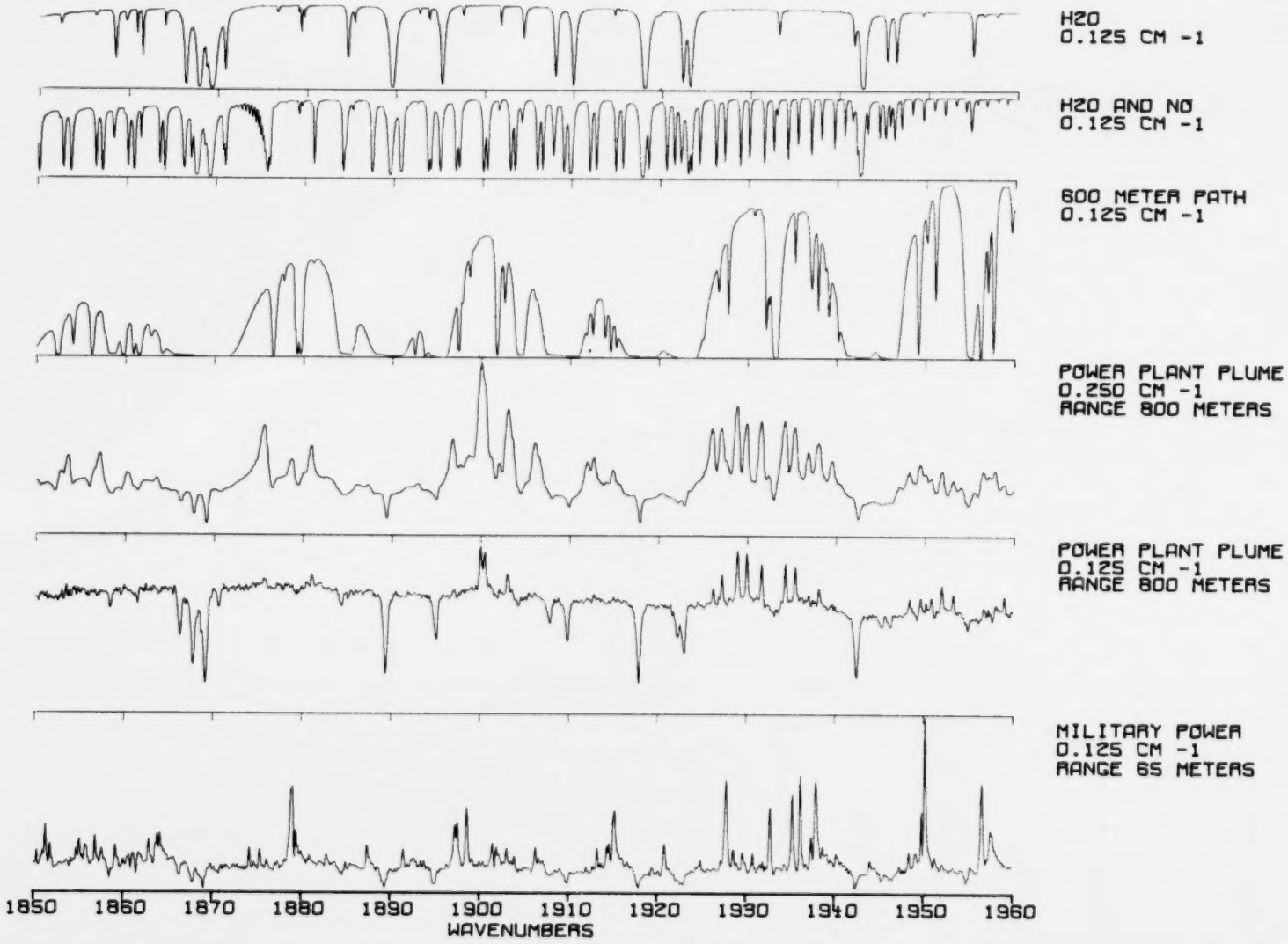

Fig. 20. Power plant and jet engine emission spectra, 1850–1960 cm^{-1}.

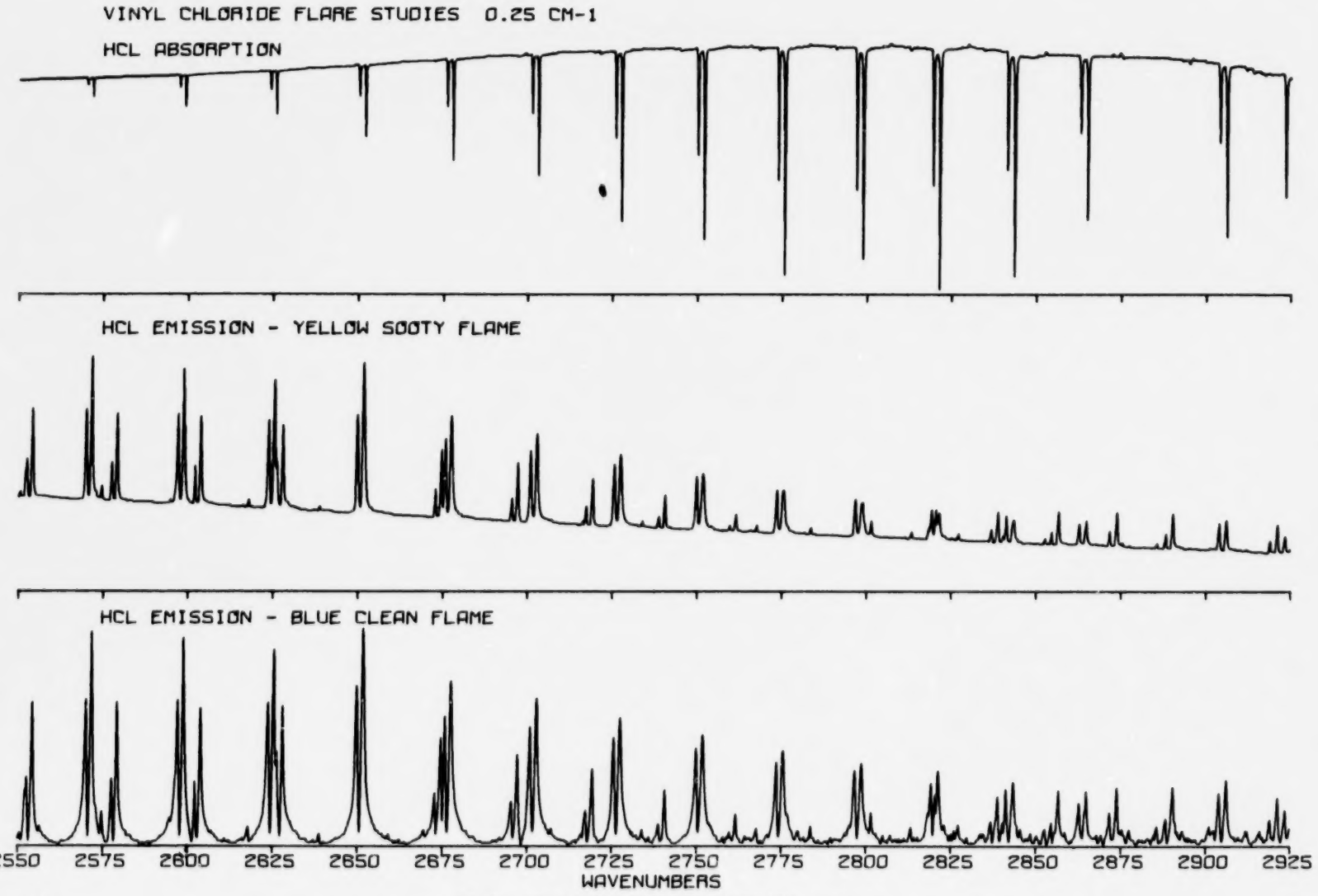

Fig. 21. Vinyl chloride flare spectra, 2550–2925 cm^{-1}.

chloride bands centered at 896 cm^{-1} and 942 cm^{-1} were observed; however, these spectra have not yet been adequately quantified due to the lack of data on the absorption coefficient of vinyl chloride as a function of temperature.

The flare did produce appreciable HCl, and emission spectra for the steam-on and steam-off conditions are shown in Fig. 21, along with an HCl absorption spectrum. Of particular interest is the unsymmetrical line shape evidence by a lack of emission in the spectral intervals between the HCl^{35} and HCl^{37} lines. A proposed explanation for these phenomena is that a resonance occurs during collisions of the HCl isotopes that results in radiationless quantum exchanges, thereby reducing the number of photons emitted between these energy levels.[12]

V. Summary

A standard laboratory-model Fourier transform spectrometer system has been installed in a van and used as a mobile instrument for obtaining the spectral signatures and concentrations of gaseous air pollutants by long-path absorption and remote emission spectroscopy. Of the various environments in which measurements have been made (rain storms, snow squalls, temperature extremes of −15–40°C, etc.), only the high vibration levels encountered in some of the jet engine measurements have adversely affected instrument operation. No significant problems have as yet been encountered due to transportation of the interferometer system. After particularly cold nights, when the internal van temperature dropped to near 0°C, it did require over an hour for the optics to stabilize when the van heating system was activated. Field data have been taken at 0.5-cm^{-1}, 0.25-cm^{-1}, and 0.125-cm^{-1} spectral resolution. The lower resolution data were taken in some cases where the particular species under study did not have resolvable fine structure in order to save time and improve SNRs. However, it has been found advisable to collect data at 0.125-cm^{-1} resolution in almost all cases since the effect of H_2O interference is always minimized, and the possibility of seeing unanticipated species is maximized by the higher resolution.

The accuracy of the long-path concentration measurements is considered to be better than ±10%. (The principal source of error is determining the pressure in the calibration cell.) There are a number of potential sources of error in determining a concentration solely from a remote emission measurement. We have not yet done sufficient work of this type, including comparison with in-stack data, to assess the measurement accuracy for this mode of operation. The lowest concentrations measured in long-path operation were on the order of 10 ppb; in the emission mode the minimum concentration for most species is probably on the order of 10 ppm. (This number is, of course, strongly dependent on source optical depth and temperature.)

Continued measurements with the ROSE system are planned during 1979. Additional measurements are needed in an airport environment and at an oil refinery. (In the latter case only a BaF_2 beam splitter was available, and the important region from 700 cm^{-1} to 850 cm^{-1} could not be observed.) Measurements on ground level flares are planned so that the flame can be observed in both emission and absorption.

The authors express their appreciation to Diane Powell, who provided assistance during the early stages of activating the interferometer system and during the gypsum pond measurements. The Nicolet Instrument Corporation, and Chuck Anderson, in particular, have been very helpful in assisting us in adapting a laboratory instrument to a field environment. The support and encouragement in the use of the ROSE System by Jack Wagman, Director of our Laboratory's Emission Measurements and Characterization Division, are also gratefully acknowledged.

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